MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY.

VOL. XC. APRIL 11, 1930. NO. 6

Dr. A. C. D. CROMMELIN, PRESIDENT, in the Chair.

The election by the Council of the following Fellows was duly confirmed :—

Samuel Forster Grace, D.Sc., Lecturer in Applied Mathematics in the University of Liverpool, Thornfield, Huyton, Liverpool ;
Theodore Mackenzie, 46 Market Street, Grahamstown, S. Africa ;
Gordon Oliver, M.Sc., Rivelin, Pwll Glas, Mold, N. Wales ;
John William Robinson Punch, Ellerstang, Castleton, Yorks ;
Theodor Martin William Strong, B.Sc., Oak Cottage, Much Hadham, Herts ; and
Henry Major Twiselton, M.A., 2 Aldworth Grove, London, S.E. 13.

The following candidates were proposed for election as Fellows of the Society, the names of the proposers from personal knowledge being appended :—

Arthur Edward Herbert Bleksley, M.Sc., Quarrywoods, Stellenbosch, S. Africa (proposed by J. Halm) ;
Don Abraham Devendra, B.A., Trinity College, Kandy, Ceylon (proposed by A. J. Bamford) ;
Charles Albert Griffiths, 165 Kingsley Road, Princes Park, Liverpool (proposed by W. H. Coombs) ;
Herbert Nicholas Jones, 25 Commercial Road, Camberwell, London, S.E. 15 (proposed by W. H. Coombs) ;
Clement Frederick Press, 191 Tufnell Park Road, London, N. 7 (proposed by W. H. Coombs) ;

grating spectrum is a normal one, the Sidmouth spectrum towards the ultra-violet will give still greater relative dispersion.

The two spectra of the Orion nebula were secured by Mitchell on the nights of 1899 February 7 and 11 with exposures of 200 and 210 minutes respectively on Seed's gilt-edge plates.

In spite of the stellar spectra on the plates, Mitchell points out that "still it is easy enough to distinguish the bright images of the nebula from the spectra of the stars." Reference to the results obtained with this instrument will be made later.

From the preceding paragraphs it will have been gathered that the Sidmouth 9-inch prismatic camera provides the greatest dispersion that has yet been employed on the Orion nebula to obtain monochromatic images, thus providing spectra which can be profitably used for determining their relative forms and intensities.

Some particulars concerning this Sidmouth instrument may be briefly stated here.

The prism and objective are both by the Brothers Henri, of Paris, and they are remarkably transparent to the ultra-violet rays. This is conspicuously so, when spectra are compared with those obtained with the 12-inch objective and prism of the McClean telescope made by (then) Messrs. Howard Grubb of Dublin. Further, the dispersion is considerable, being 46·0 mm. between $H\beta$ and $H\delta$, so that the monochromatic images of the Orion spectrum overlap slightly in only two cases.

Owing to certain constructional instrumental details the exposure was practically limited to 4 hours 50 minutes or 290 minutes.

The smallness of the finder prevented more efficient following.

The table given below sums up the data for the longest exposures made which are concerned in the present discussion.

Details of Negatives.

Neg.	Date.	Exposure. Time (U.T.). h m h m	Duration. (Min.)
1312	1929 Oct. 31	0 25– 3 50	205
1315	,, ,, 31	23 48– 3 18	210
1330	,, Dec. 2	21 37– 1 37	240
1332	,, ,, 29	19 40–23 20	220
1333	,, ,, 31	20 17–23 45	208
1334	1930 Jan. 5	18 25–21 20	175
1336	,, ,, 20	18 13–22 27	254

From the above table it will be seen that the maximum possible length of exposure was unfortunately in no instance secured.

In every case the photographic plate used was the Ilford "Iso-Zenith" (H and D 700). This plate is very sensitive well into the ultra-violet, but on the red side of $H\beta$ (λ 4861) it begins to fall away at λ 4924 and more rapidly at λ 5019.

Three of the above negatives, namely, numbers 1336, 1330, and 1333, which have been enlarged 1·8 times, are reproduced in Plate 11, together

with ζ Tauri as a comparison spectrum. This star is of magnitude 3·0 and spectral type B3neγ. The $H\beta$ line has bright components on each side of the absorption line, thus reducing very considerably the appearance of the absorption in this line.

Wright in his paper on the spectra of gaseous nebulæ gives a list of the wave-lengths and relative intensities of the lines in the Orion nebula spectrum taken with the glass slit spectrograph attached to the 36-inch Lick refractor with correcting lens. As only the brighter lines are referred to in this discussion, those of intensity less than ten have been omitted here.

These data are given in Table I. in columns 2 and 5 respectively. To compare these intensities with others taken with another slit spectrograph, but in this case with a reflector, the results obtained by Sir Norman Lockyer * in 1890 with the 30-inch reflector have been added in column 6. His intensities were originally given on a scale of 6 as maximum, but they have been computed here for a maximum of 100.

The arrangement of the table is not in order of wave-lengths but of intensities of images as expressed by Mitchell from his grating photographs which are given in column 3. In addition to the above, column 4 shows the intensities of the nebular images as estimated from the Sidmouth prismatic camera negatives, and column 1 the chemical origins of the lines.

TABLE I.

Table of Intensities.

Origin.	λ.	Mitchell Concave Grating.	Lockyer Pris. Cam.	Wright 36-in. Refr. Slit Spec.	J. N. Lockyer 30-in. Refl. Slit Spec.
(1).	(2).	(3).	(4).	(5).	(6).
$H\gamma$	4340·62	100	90	100	100
$H\beta$	4861·50	80	100	70	100
O II	3726·38	80	40	40	100
O II	3729·10			30	
O III (N1)	5007·01	80	80	70	80
$H\delta$	4101·93	20	70	60	100
O III (N2)	4959·09	20	60	50	60
$H\varepsilon$	3970·27	10	50	40	80
..	3868·85	5	30	40	60
Hζ	3889·17	5	20	40	60
He	4471·8	3	10	20	60
$H\eta$	3835·7	3	10	15	30
$H\theta$	3798·1 *	2	..	10	30
He	4026·5	1	10	10	50
..	3967·62 *	..	..	30	..
He	3965·1 *	..	..	10	..

* *Proc. Roy. Soc.*, **48**, 194, 1894.

The lines in the table marked with an asterisk do not appear on the Sidmouth plates, while those of helium at λ 4472 and λ 4026, and $H\eta$, are barely visible. The origins of some of the nebular lines given above are those discovered by I. S. Bowen.*

The outstanding feature of the spectrum, as can be seen from Plate 11, is the great size of the image at λ 3727 in relation to all the others. The next in extent are $H\beta$ and $H\gamma$, both of them being of about equal size. Omitting the other lines of the hydrogen series, which gradually decrease in size as the violet is approached, the nebular image at λ 5007 comes closely next, followed by λ 4959, and lastly λ 3869.

Before any statement can be made regarding the intensities of the various monochromatic images it is necessary to adopt some nomenclature for the different regions for identification purposes.

This can best be accomplished by reproducing on a small scale the very excellent drawing of the nebula as observed visually by G. P. Bond † from 1859 to 1863, and marking on it the various regions to which attention is desired to be drawn. From this illustration the orientation of the various monochromatic images in the spectra can also be easily deduced (see Plate 12).

This drawing has been reduced to fit approximately the scale of the nebular images, which in this plate have been enlarged 3 times from the original negative.

Thus (H) denotes the Huyghenian Region, the brightest part of the nebula. (M) is the Messierian branch or Proboscis Major, which is the large, bright, scimitar-looking streamer in the south-eastern quadrant. (F) denotes the dark space on the eastern side of the Huyghenian Region and termed the Sinus Magnus. The letter (C) is to represent the lower portions of the curved streamers emanating from the north-west side of the Huyghenian Region, and (B) the region just beyond. (E) is the region just to the west of (C), and lastly (D), the southern corner of the Huyghenian Region (H).

Coming now to the determination of the relative intensities of the different specified regions in the spectral images, a table was formed (Table II.) for each region for the various wave-lengths, 10 representing that portion of the section in each area which was considered most intense. A question mark was inserted when overlapping images prevented any decision being made.

Table II.

Intensities of the Images in Different Regions.

	λ 3727.	Hβ.	Hγ.	λ 5007.	λ 4959.
Huyghenian Region (H)	2	9	8	10	6
Messierian Branch (M)	10	8	7	2	0
N.W. Streamers (C)	10	8	7	?	1
N.W. Outliers (B)	10	2	1	?	0
W. Outliers (E)	10	1	1	1	?
Branch at S.W. Corner of Huyghenian Region (D)	10	2	2	0	0

* *Nature*, **120**, 473, 1927.

† *Wash. A.O.*, 1878, Appendix 1.

λ 3727.
Hβ. N2. N1.
B C H D S
W E F M E
N

Digitized by the Internet Archive
in 2026

https://archive.org/details/monthly-notices-of-the-royal-astronomical-society_1930-04-11_90_6

From the above table and a perusal of the spectra reproduced in Plate 11 it will be seen that the Huyghenian Region (H) is the only one in which the image at λ 3727 does not predominate, and in this it is the weakest of them all. This region is thus chiefly formed by λ 5007, λ 4959, and hydrogen.

The Messierian branch (M) is fairly strong in both λ 3727 and hydrogen. At (C) the radiation is chiefly λ 3727 with hydrogen to a slightly lesser degree. In the region at (B) the image is practically all formed by λ 3727, while the same may be said of the region (E) well west of the Huyghenian Region (H).

Extending from the southern corner of the Huyghenian Region (H) a prominent long arm, directed towards the south-west from (D), is very strong in λ 3727 radiation, but only very faintly visible in parts in the hydrogen and λ 5007 images.

A comparison of the above results of intensity and size may now be made with a series of statements summed up by Mitchell from his own photographs taken with a grating (Table III.).

TABLE III.

	Mitchell.	Lockyer.
Brightest image	$H\gamma$	$H\beta$
Trifle fainter	$5007 = H\beta = 3727$	$H\gamma > 5007 > 3727$
Greatest image	3727	3727
Extent of $H\gamma$ image	$= H\beta$	$< H\beta$
Hydrogen Series appears down to	$H\varrho$	$H\eta$
Intensity in Huyghenian Region	$5007 > H\beta$	$5007 > H\beta$
,, ,, outlying region	$H\beta > 5007$	$H\beta > 5007$
In Huyghenian Region—		
Equally intense	3727 and $H\beta$	3727 (Int. 2) $H\gamma$ (Int. 8)
Slightly stronger	$H\gamma$	$H\beta$ (Int. 9)

While in the main the results are in fair agreement there are some outstanding differences.

The first is, that on the Sidmouth negatives, while the difference is small, $H\beta$ is more intense and extensive than $H\gamma$.

Again, in the Huyghenian Region (H) the order of diminishing intensity is as shown in Table II., namely, 5007, $H\beta$, $H\gamma$, 4959, and lastly 3727. Mitchell brackets 3727 and $H\beta$ as being of equal intensity. Even if allowance be made for a very considerable reduction in the sensitiveness of the plate at the wave-length of 3727, such a large divergence from the Sidmouth negatives can only be explained by the difference in the kinds of instruments employed.

In the first two items of Table III. it is difficult to determine the order of the brightest images as intensity varies so much in their different regions and their sizes are not the same. Thus all the images, 5007, $H\beta$, and $H\gamma$, have denser regions in them than any in λ 3727, but the last mentioned image is half as large again as any of them. If one

were to select the images which contain the greatest areas of strong density, then their order of diminishing intensity would probably be that in Table I., column 4.

It is interesting to note that if the image at λ 3727 is as bright as $H\beta$ and λ 5007, as Mitchell states it is, then an ordinary direct photograph of the nebula taken with a reflector should assume the form of the image at λ 3727, which is much more extensive than those of $H\beta$ or λ 5007 (see Plate 12).

Now Dr. Isaac Roberts in 1886 took and published three photographs of this nebula, one of which had a short exposure of 15 minutes. This was secured with his 20-inch reflector of 98 inches focal length, and is here reproduced in the bottom right-hand side of Plate 12, reduced approximately to the scale of the spectral images.

It will be seen that this picture displays only the Huyghenian Region (H), the lower portions of the curved streamers at (C), the short streamers just to the west of (D), and the Messierian branch (M).

Thus this picture closely resembles Bond's drawing and the images of $H\beta$, 5007, and 4950, showing that it is chiefly built up of these radiations. This is corroborated by Keeler's * observation, which stated that "when the intensity of the Huyghenian Region is the same in each case (with and without screen), the intensity of the remoter parts of the nebula and outlying streamers is very much less in the photograph taken with the colour screen on orthochromatic plates."

If a longer exposure had been given, then the picture would have picked up the fainter but more extensive image of λ 3727, and the form then would have assumed one like λ 3727, with those of $H\beta$ and the other two nebular images superimposed on it, as is indicated in the longer-exposed pictures.

Such a longer-exposed photograph, reduced to the scale of Roberts's, is here reproduced for comparison (see Plate 12, bottom, left). The long exposure by Roberts is not sufficiently well illustrated in his volume on nebulæ † for reproducing here, so that the plate accompanying the memoir on Keeler's ‡ photographs has been reduced instead. This photograph was also taken with a reflector, the Crossley reflector, with an exposure of 40 minutes. This photograph illustrates the greater extension of the nebula in the north-west and western regions, where the image at λ 3727 is most extended.

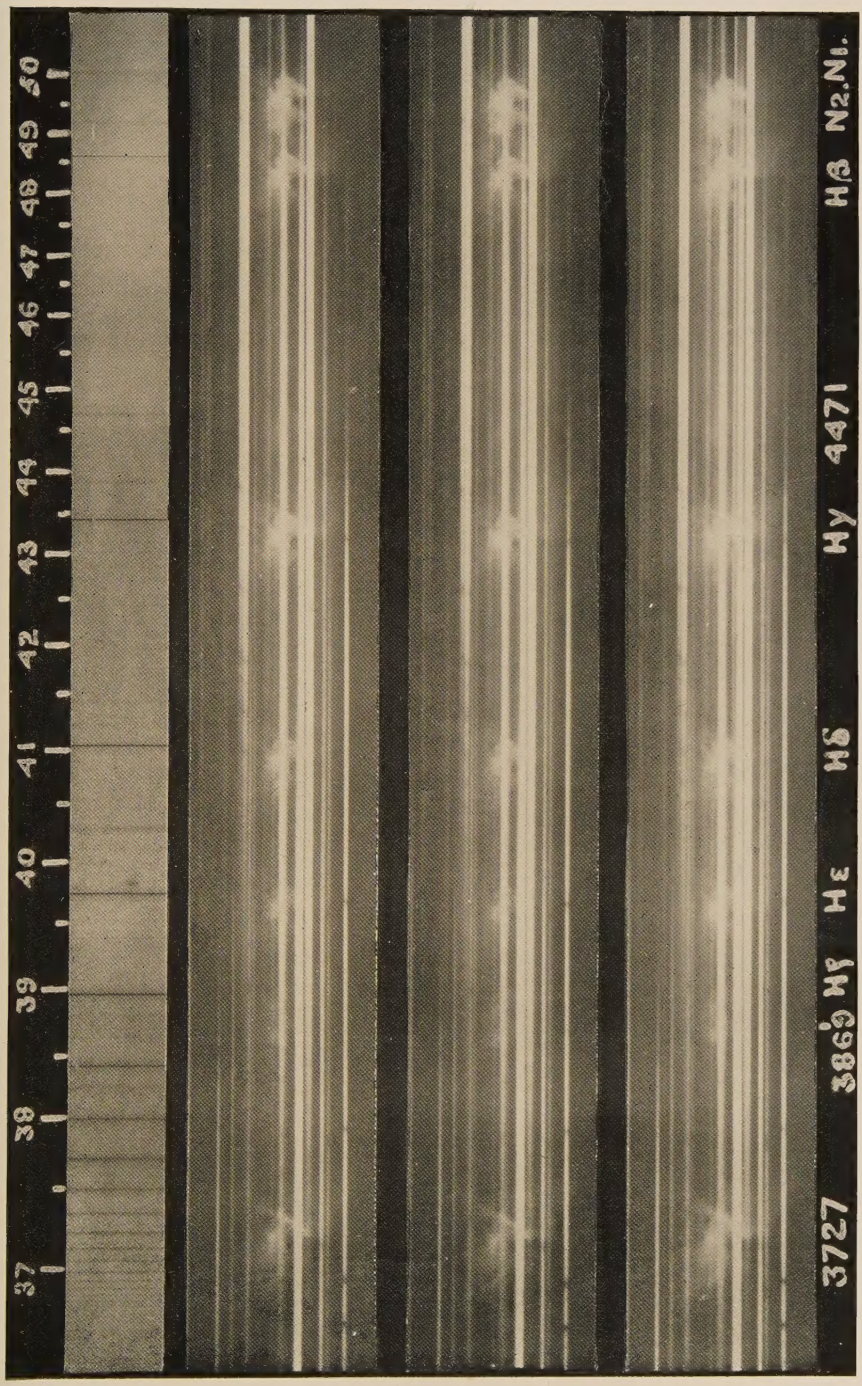
In comparing the nebular images in the Sidmouth spectra with the results obtained by the use of screens no useful purpose would be served by treating the subject in detail. It will suffice to state that the Sidmouth photographs endorse in the main the deductions made by Keeler, Hartmann, and Reynolds.

None of the observers who used screens could completely isolate each of the images formed by $H\beta$, λ 5009, and λ 4959. It is only the concave grating or prismatic camera instruments that can accomplish this.

* *Ap. J.*, **9**, 140, 1899.

† *A Selection of Photographs of Stars, Star-clusters, and Nebulæ.* The Universal Press, 1893.

‡ *L.O. Pub.*, **8**, pl. 10, 1908.


37
38
39
40
41
42
43
44
45
46
47
48
49
50
3727
3869 Hζ Hε
Hδ
Hγ 4471
Hβ N2.Ni.

The outstanding feature of the image at λ 3727 is that it chiefly favours the outlying regions of the nebula of Orion. This radiation, as Eugen von Gothard * early (1892) pointed out, is always very intense in the large irregular nebulæ and always very faint in the planetary nebulæ, indicating a considerable difference between the two. Von Gothard secured his photographs with a 10-inch prism in front of a $10\frac{1}{4}$-inch reflector, so that the ultra-violet region was well pronounced. Wright † at a much later date (1918) drew attention to the peculiar tendency of this image to favour the outer regions of some nebulæ, and this is well shown in some of the fine reproductions of his spectra.

Its external position with regard to the nebula is somewhat similar to that of the corona of the sun, the origin of which is unknown.

Summary.

This paper is a study of the monochromatic images of the Orion nebula, as exhibited in spectra taken at the Norman Lockyer Observatory last winter with a 9-inch prismatic camera of large dispersion.

Reference is made to earlier researches by Pickering and Mitchell which were accomplished with spectrographic instruments of much smaller dispersion.

A brief description of the instrument used, the negatives secured, the wave-lengths and intensities of the images derived, and a comparison with prior researches are given.

The monochromatic images show that the radiation from the central portion of the nebula, namely, the Huyghenian Region, is almost entirely due to hydrogen and the two well-known nebular lines N1 and N2 now traced to *O* III; that from the Messierian branch is due to the above together with λ 3727 or *O* II; and that from the outlying regions is almost solely composed of λ 3727.

These conclusions endorse in the main the earlier researches and also those made by Keeler, Hartmann, and Reynolds, who employed specially prepared screens.

Two plates accompany the paper, one giving three enlarged representations of the nebula spectrum with an accompanying stellar spectrum for comparison, and the other enlarged nebular images of the chief radiations with visual and photographic pictures of the nebula itself.

Description of the Plates.

PLATE 11.

Three reproductions, enlarged 1·8 times, from separate negatives of the Orion nebula taken on 1930 January 20, 1929 December 2 and 31, with exposures of 254, 240, and 208 minutes respectively. The comparison spectrum at the top is ζ Tauri of magnitude 3·0 and spectrum type B3neγ, the chief lines being hydrogen and helium. $H\beta$ appears much less intense than $H\gamma$ because it is bounded on each side by bright components.

* *A. and Ap.*, **12**, 55, 1893.
† *L.O. Pub.*, **13**, 255, pt. vi., 1918.

PLATE 12.

Threefold enlargements of the nebular images at λ 3727 (left) and $H\beta$, λ 4959, and λ 5007 (right) compared with (between them) a reduced copy of Bond's drawing of the nebula made from visual observations. Below, in the middle, a key-map indicating the regions mentioned in the text and also the orientation of all the images.

There is also given (below) on the right a short exposure (15 minutes) of the nebula by Dr. Isaac Roberts and on the left a longer exposure (40 minutes) by Keeler, both taken with reflecting telescopes and here reduced to the same scale.

The Mechanics of the Emission of Bright Hydrogen Lines in the Gaseous Nebulæ. By J. A. Carroll, M.A., Ph.D., Assistant Director, Solar Physics Observatory, Cambridge.

(*Communicated by the Director.*)

Introduction.—The present investigation has for its object the elucidation of the mechanism governing the emission of lines of the Balmer series of hydrogen in the gaseous nebulæ; in particular, the temperature and state of ionization and excitation are discussed, and attempts are made to obtain numerical values.

The paper is based on some experimental work of H. H. Plaskett (1). In his paper certain deductions are drawn from the data he obtained, but his conclusions are to a great extent invalidated by errors in his equations. The present work corrects these and extends and supplements his investigation.

Specification of the Problem.—In the nebulæ the existence of the so-called "forbidden" lines establishes the facts that (*a*) the density is low, as shown by Bowen (2), in order that the atoms may be undisturbed by collisions; and (*b*) that the stimulation by radiation is very weak, as shown by Eddington (3), in order that the atoms may be undisturbed by processes of absorption—that is to say, collisions are rare in the life of an excited atom, even if it be metastable, with other atoms, electrons, or quanta.

Thus the processes that can affect a hydrogen atom are (1) capture of an electron by an ionized atom; (2) excitation from the normal state by electron collision or by absorption of a line of the Lyman series; (3) ionization, photo-electric or by electron collision.

In forming our equations we make use only of the hypothesis of "preservation"—that is to say, the numbers of atoms, electrons, or quanta of any particular specification remain constant. The principle of detailed balancing would lead to more definite conclusions in certain cases, but in view of the scarcity of our knowledge of the conditions obtaining and the inaccuracy of the data available, it seems inadvisable at the present juncture to press the matter. It is intended to pursue the theoretical investigations further in another communication.

Let N_s be the number of hydrogen atoms per c.c. in a state of total quantum number s at any moment.

N be the number of hydrogen atoms "created" per c.c. per sec. in all excited states.

p_s be the fraction of these N excited atoms created in the s quantum state.

A_{sr} be the probability of a transition by an atom from state s to state r in one second, resulting in the emission of radiation of frequency ν_{sr}.

$\mathbf{A}_s$ be the sum of the probabilities of transitions from state s to all lower states; *i.e.* $\mathbf{A}_s = \sum_{r=1}^{s-1} A_{sr}$.

s be the total quantum number of a state.

By the number N of atoms "created" in excited states we mean the atoms so formed by excitation from a lower state in any way, by the capture of an electron by an ionized atom, or in any way *except by the process of falling from a higher state with the emission of radiation.* In a steady state all these numbers are constants.

Then whatever the means of generation of excited atoms may be, we have the following equations on the assumption that collisions or absorptions are so rare for excited atoms that they all return to the ground state undisturbed, and that this is so may be seen as follows :—

Collision Frequency.—We will take 10^{-20} gms./c.c. as the mean density and 1000 particles per c.c., of which we will take, say, 500 to be electrons and 20 per cent. of the remainder to be hydrogen, *i.e.* 100 hydrogen atoms per c.c. These figures are of the right order of magnitude; their precise value, it will be seen, is, for our purpose, immaterial. We will take the effective diameter of the hydrogen atoms to be 10^{-7} cms. to be on the safe side. Then, if l be the mean free path,

$$2{\cdot}25 \times 10^{12} > l > 2{\cdot}25 \times 10^{11} \text{ cms.};$$

the average velocity of a hydrogen atom is $1{\cdot}57 \times 10^4\sqrt{\mathrm{T}}$ cms./sec., the average velocity of an electron is $6{\cdot}23 \times 10^5\sqrt{\mathrm{T}}$ cms./sec., so the average duration of a free path is of the order $10^7/\sqrt{\mathrm{T}}$ secs. For all likely temperatures this is over 10^4 seconds, and the mean life of excited hydrogen atoms is 10^{-5} seconds or less, so that our assumption about the insignificance of collisions in removing atoms from excited states is justified. We shall show later that the same is true of radiation. As a use can be made of this fact, considered as established by the existence of "forbidden" lines, we shall merely state it here as one of the necessary conditions.

Now

$N_s\mathbf{A}_s$ = number of atoms leaving state s per second.
= ,, ,, ,, arriving at state s per second.
= ,, ,, ,, created in state s per second.
+ ,, ,, ,, falling to state s per second from higher states.
$= Np_s + \sum_{r=1}^{\infty} N_{s+r}A_{s+r,\,s}$.

Thus

$$N_s = N\frac{p_s}{\mathbf{A}_s} + N_{s+1}\frac{A_{s+1,\,s}}{\mathbf{A}_s} + N_{s+2}\frac{A_{s+2,\,s}}{\mathbf{A}_s} + \quad . \quad . \quad \text{(i)}$$

$$N_{s+1} = N\frac{p_{s+1}}{\mathbf{A}_{s+1}} + N_{s+2}\frac{A_{s+2,\,s+1}}{\mathbf{A}_{s+1}} + \quad . \quad . \quad \text{(ii)}$$

$$N_{s+2} = N\frac{p_{s+2}}{\mathbf{A}_{s+2}} + \quad . \quad . \quad \text{(iii)}$$

etc.

Multiply both sides of (ii) by $\frac{A_{s+1,\,s}}{\mathbf{A}_s}$, both sides of (iii) by

$$\left\{\frac{A_{s+1,\,s}}{\mathbf{A}_s}\cdot\frac{A_{s+2,\,s+1}}{\mathbf{A}_{s+1}} + \frac{A_{s+2,\,s}}{\mathbf{A}_s}\right\},$$

and correspondingly for succeeding equations, so that on adding the coefficients of N_{s+r} are the same on both sides for all $r \geqslant 1$, and we obtain

$$N_s = N\sum_{r=0}^{\infty} p_{s+r}\Pi_{s+r,\,s},$$

where Π is a function of the transition probabilities and is defined by the recurrence formula

$$\Pi_{s+r,\,s} = \frac{1}{\mathbf{A}_{s+r}}\{\Pi_{s,\,s}A_{s+r,\,s} + \Pi_{s+1,\,s}A_{s+r,\,s+1} + \ . \ . \ . + \Pi_{s+r-1,\,s}A_{s+r,\,s+r-1}\}$$

and

$$\Pi_{ss} = 1/\mathbf{A}_s,$$

$$\Pi_{s+1,\,s} = \frac{1}{\mathbf{A}_{s+1}}\cdot\Pi_{ss}A_{s+1,\,s} = \frac{A_{s+1,\,s}}{\mathbf{A}_{s+1}\mathbf{A}_s}.$$

In Table I. are given the transition probabilities A_{rs}. These are taken from Slack's paper ([4]), and are absolute values of the probability

TABLE I.

*Transition Probabilities A_{rs}.**

r \ s	1.	2.	3.	4.	5.	6.	$\mathbf{A}_r$.
	$\times 10^7$	$\times 10^7$	$\times 10^7$	$\times 10^5$	$\times 10^5$	$\times 10^5$	$\times 10^7$
3	5·64	4·42	..	..	..	..	10·06
			..				
4	1·28	·845	·904	..	..	..	3·029
5	·412	·254	·221	27·3	..	..	1·160
6	·173	·102	·079	7·68	9·88	..	·530
7	·086	·046	·034	3·67	3·52	4·18	·279

* These values are taken from a computation by Slack ([4]) on the basis of the wave mechanics and are absolute values.

of the spontaneous transition of an atom from state r to state s in one second, *assuming that the atom is equally likely to be in any one of the*

r^2 *sub-states into which its upper state can be resolved, e.g.* by a magnetic field. It is necessary in using these coefficients, then, to ensure that the mode of generation of excited atoms does not violate this condition, or at any rate to bear in mind that it is assumed to be true. It is not true, for example, for the creation of excited atoms by Lyman absorption, for since the ground state of the hydrogen atom is $1\,^1S$, the only possible transitions are to higher ^1P states. For a P state l (the azimuthal number) is 1 and the sub-states $(2l + 1)$ are 3, so that only $3/r^2$ of the sub-states are occupied. In Slack's paper the transition coefficients are given for all the separate azimuthal quantum numbers for any given total quantum number, and instead of the A's in Table I. we must use those corresponding to P to S or D transitions only in investigating Lyman absorption for example.

In Table I. the values of $\mathbf{A}_r$ are also given in the last column, and in Table II. the values of $\Pi_{r,\,s}$ computed according to the formula derived above.

TABLE II.

Values of $\Pi_{r,\,s}/10^8$.

r \ s	3.	4.	5.	6.	7.
3	·994	·296	·258	·239	·228
4	..	3·300	·776	·623	·624
5	..	..	8·620	1·607	1·325
6	..	..	..	18·890	2·82
7	..	..	..	..	35·78

Since the nebula is transparent to its own radiation *of subordinate series lines* (such as the Balmer lines), the intensity of a line is simply proportional to the number of transitions taking place per second. Thus for any Balmer line resulting from a transition from state s to state 2, if I_{s2} be its intensity

$$\mathrm{I}_{s2} = \mathrm{N}_s h\nu_{s2}\mathrm{A}_{s2}$$

or

$$\mathrm{I}_{s2} = \mathrm{N}h\nu_{s2}\mathrm{A}_{s2}\sum_{r=0}^{\infty} p_{s+r}\Pi_{s+r,\,s} \quad . \quad . \quad . \quad (1)$$

These equations replace equations (5) of Plaskett's paper, which are incorrect. In equation (1) above $h\nu_{s2}\mathrm{A}_{s2}$ is multiplied by N_s or $\mathrm{N}\sum_{r=0}^{\infty} p_{s+r}\Pi_{s+r,\,s}$, which is the number of atoms *in* state s at any time (assumed constant for a steady state). In Plaskett's equations $h\nu_{s2}\mathrm{A}_{s2}$ is multiplied by a quantity $\mathrm{N}\left\{p_s + \sum_{r=1}^{\infty} p_{s+r}\mathrm{P}_{s+r,\,s}\right\}$, where the p's have the same meaning as in this paper and the P's resemble the Π's of this paper. Plaskett's multiplier, however, is not N_s but the number of atoms *arriving* at state s per second, *i.e.* (since this must be the same as

the number leaving) it is $N_s \cdot \sum_{r=1}^{s-1} A_{s,r}$. or $N_s \mathbf{A}_s$. This has led to incorrect numerical coefficients in his equations and to values of p_s which increase somewhat with s, instead of decreasing rapidly as do the values obtained from equation (1). Equation (1) represents the correct physical statement that the intensity or the number of transitions is proportional to the number of atoms *actually in a given state* multiplied by the transition probability.

This leads to an alternative form of equations (1), but it may be remarked in passing that my equations (1) are symmetrical and homogeneous, and that my Π's (replacing Plaskett's P) are so also.

The alternative form is a set of equations for p in terms of I. This is clearly preferable, since then the unknown quantities p are expressed in terms of the sum of a series involving only the observed quantities I and known coefficients.

We have

$$\frac{I_{s2}}{A_{s2}h\nu_{s2}} \cdot \mathbf{A}_s = \text{number of atoms leaving state } s \text{ (\textit{i.e.} number in state } s \times \text{transition probability } \mathbf{A}_s) \text{ per second.}$$
$$= \text{number arriving.}$$
$$= Np_s + \sum_{r=1}^{\infty} \frac{I_{s+r,\,2}}{A_{s+r,\,2}h\nu_{s+r,\,2}} A_{s+r,\,s}$$

or

$$Np_s = \frac{I_{s2}\mathbf{A}_s}{A_{s2}h\nu_{s2}} - \sum_{r=1}^{\infty} \frac{I_{s+r,\,2}}{A_{s+r,\,2}h\nu_{s+r,\,2}} A_{s+r,\,s} \quad . \quad . \quad (2)$$

If α, β, γ, δ, ϵ represent the intensities of H_α, H_β, H_γ, H_δ, and H_ϵ respectively, equation (1) leads to

$$\left.\begin{aligned} \alpha &= 672p_3 + 200p_4 + 174p_5 + 161p_6 + 154p_7 \\ \beta &= \quad 57p_4 + 135p_5 + 108p_6 + 108p_7 \\ \gamma &= \quad\quad 50p_5 + \quad 94p_6 + \quad 78p_7 \\ \delta &= \quad\quad\quad\quad 469p_6 + \quad 70p_7 \\ \epsilon &= \quad\quad\quad\quad\quad\quad 414p_7 \end{aligned}\right\} \quad . \quad (1a)$$

Or, in the alternative form, equation (2) leads to

$$\left.\begin{aligned} p_3 &= 1491\alpha - 520\beta - 424\gamma - 318\delta - 294\epsilon \\ p_4 &= \quad 1746\beta - 467\gamma - 310\delta - 318\epsilon \\ p_5 &= \quad\quad 1980\gamma - 398\delta - 304\epsilon \\ p_6 &= \quad\quad\quad\quad 2135\delta - 362\epsilon \\ p_7 &= \quad\quad\quad\quad\quad\quad 2390\epsilon \end{aligned}\right\} \quad . \quad (2a)$$

In the form (1*a*) it is not clear that we can safely ignore values of p_s above a certain s unless we have a guarantee that they diminish rapidly, and that $\sum_{s=r}^{\infty} p_s$ is bounded for some $r \geqslant r_0$ say. Now we have

no such information; it is this that we seek to discover. It is possibly true but should not be assumed. It should be noted that the correct coefficients in (1*a*) decrease only very slowly after the first term, and Plaskett's argument does not apply.

Equations (2*a*) are better suited to the purpose, for we can say, basing our approximation on observational evidence, (1) that no term after δ, say, is greater than about 50 per cent. of it, and that they do decrease in all probability; and (2) the total intensity for all lines beyond H_δ is small compared with the preceding intensities. Moreover, the leading coefficients are large compared with succeeding ones, and get larger as s increases.

Plaskett's method of solving his equations is not clear, and his remarks about obtaining an approximate solution by taking four quantities in brackets, which are the sums of series of p's, as equal are not applicable, since to find even the relative values of p_3, p_4, p_5, and p_6 the quantities in brackets must be taken to be strictly zero. Moreover, the p's found from his equations actually increase with increasing s, which tends to vitiate his argument. It will be seen that the correct equations lead to a rapid decrease in the value of p as s increases, so that in (1*a*) or (2*a*) we can safely ignore terms beyond p_6, especially as the coefficient of the leading term is large compared with succeeding coefficients; but for safety we could replace p_6 by a quantity C, which represents p_6 plus the effect of later terms. Fortunately the decrease is so rapid that C is effectively p_6, and in any case the accuracy of the data is insufficient to render the distinction very necessary.

The numerical results of the solution of the equations are given in Table IV. Plaskett's observational data are reproduced for convenience in Table III.

Table III.

Line.	N.G.C. 1976.	N.G.C. 2440.	N.G.C. 3242.	I.C. 3568.	I.C. 4593.	N.G.C. 6790.	N.G.C. 7027.	N.G.C. 7662.
*N*II 6584	..	..	..	..	..	..	26	
H_α 6563	40	..	..	..	..	..	58	
N_1 5007	33	..	..	..	..	..	118	
N_2 4959	12·7	44	32	..	14·4	..	42	32
H_β 4861	10·0	10·0	10·0	10·0	10·0	10·0	10·0	10·0
He II 4686	..	6·2	2·4	..	..	..	3·8	6·0
O III 4363	..	..	0·9	1·6	..	1·4	2·2	1·9
H_γ 4340	4·8	3·5	4·1	4·8	5·6	3·9	3·4	3·9
H_δ 4102	1·9	..	1·8	2·0	2·6	1·1	1·5	1·9

Table IV.

The Relative Numbers of the Creations of Excited Atoms.

Nebula.	1976.	2440.	3242.	3568.	4593.	6790.	7027.	7662.	Mean.	A_r/A_4.	$\frac{64}{r^3}$.
p_3	3·56	..	..	..	..	..	5·15	..	4·41	3·33	2·36
p_4	1·00	..	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00
p_5	0·60	..	0·49	0·59	0·72	0·49	0·40	0·47	0·54	0·38	·51
p_6	0·27	..	0·25	0·29	0·39	0·16	0·21	0·27	0·27	0·18	·29

Equations (1) or (2), it should be observed, hold whatever the mechanism of generation of excited atoms may be, and are fundamental in a discussion of the mechanism. They do, however, contain the assumption that all atoms created in state s and not descending to it from a higher state are equally likely to occur in any one of the s^2 possible sub-states of that level. Of these sub-states it may be remarked there are $2l + 1$ to a state of azimuthal quantum number l, where l equals 0 for all S states, 1 for all P states, 2 for all D states, and so on. There is no reason to suppose this is not true for any process of electron capture or excitation by collision, but it is not true for such a process as Lyman absorption, for by this process atoms can only be created in P states, since the ground state is a single S state. We shall go into this later and derive the appropriate modified equations. This point seems to have been overlooked by Plaskett, and equations such as he propounds cannot in practice be derived. We shall reject Lyman absorption as an important mechanism but not for his reasons, which, while probably true under the circumstances obtaining in nebulæ, are not necessarily so.

There is also another calculation that can be made concerning the excited atoms, and that is of the relative numbers actually in a given state s at any moment.

$$I_{s2} = N_s h\nu_{s2} A_{s2},$$
$$\therefore N_s = I_{s2}/h\nu_{s2} A_{s2}.$$

These numbers are given in Table V.

TABLE V.

Relative Numbers of Atoms in Different Excited States.

$100\ N_s/N_4$.

Nebula. / s	1976.	2440.	3242.	3568.	4593.	6790.	7027.	7662.	Mean.
3	103	..	..	..	..	..	149	..	126
4	100	100	100	100	100	100	100	100	100
5	142	104	122	142	166	115	101	115	126
6	133	..	125	140	182	77	105	132	128

The Equations for Lyman Absorption.—When any process is considered which involves the creation of excited atoms in a given state s not uniformly distributed among sub-states, the equations of equilibrium can, of course, be developed for any arbitrary assignment of the creations to the sub-states of different l, or even j, but they are so complicated as to be almost unmanageable, and since we cannot investigate the fine structure of hydrogen lines emitted from the nebulæ, we cannot find the data needed to solve the equations in the general case, so that it has seemed better to proceed in a different manner. An examination of the numerical magnitudes involved shows that atoms created in the higher states have comparatively little influence on the lower states, at any rate if they be created in P states only, since, for example, about 80 per cent. of them go straight back to the ground state and most of the remainder to state 2.

I have accordingly ignored all creations above the seventh state and have worked out in detail numerically, using Slack's ([4]) data, the transitions for atoms created in all P states up to and including the seventh. Fig. 1 illustrates this.

We obtain for transitions giving rise to Balmer lines from p_s atoms created in state sP,

$$\begin{aligned}
7\rightarrow 2 &\quad \cdot 111p_7,\\
6\rightarrow 2 &\quad \cdot 001p_7 + \cdot 116p_6,\\
5\rightarrow 2 &\quad \cdot 005p_7 + \cdot 003p_6 + \cdot 114p_5,\\
4\rightarrow 2 &\quad \cdot 010p_7 + \cdot 012p_6 + \cdot 011p_5 + \cdot 120p_4,\\
3\rightarrow 2 &\quad \cdot 039p_7 + \cdot 047p_6 + \cdot 041p_5 + \cdot 042p_4 + \cdot 117p_3.
\end{aligned}$$

These are the correct right-hand sides of equation (1) in this case.

Whence the equations for creations in P states only, corresponding to 1 and 2 in the case of "general creation," are, ignoring states above the seventh,

$$\left.\begin{aligned}
\alpha &= 403p_3 + 144p_4 + 141p_5 + 162p_6 + 134p_7\\
\beta &= \quad\quad 240p_4 + \quad 22p_5 + \quad 24p_6 + \quad 20p_7\\
\gamma &= \quad\quad\quad\quad\quad 131p_5 + \quad 3p_6 + \quad 6p_7\\
\delta &= \quad\quad\quad\quad\quad\quad\quad\quad 84p_6 + \quad p_7
\end{aligned}\right\} \quad . \qquad (3)$$

TABLE VI.

Creations of Excited Atoms by Lyman Absorption.

Nebula.	1976.	2440.	3242.	3568.	4593.	6790.	7027.	7662.	Mean.	A_r'/A_4'.
p_3	178	..	..	..	..	..	306	..	242	232
p_4	100	..	100	100	100	100	100	100	100	100
p_5	101	..	85	101	120	79	68	80	91	51
p_6	63	..	59	65	89	35	48	62	60	31

The numbers of atoms *created* in the different states by this process obtained from the solution of equations (3) in a manner similar to the other values obtained from equations (1) or (2) are given in Table VI., and the numbers N_s in those states in Table VII.

TABLE VII.

Relative Numbers in Different States for Lyman Absorption.
$100\ N_s/N_4$.

Nebula. / s	1976.	2440.	3242.	3568.	4593.	6790.	7027.	7662.	Mean.
3	232	..	..	..	..	..	336	..	288
4	100	100	100	100	100	100	100	100	100
5	85	63	73	86	100	70	61	70	76
6	52	..	49	55	71	30	41	52	50

Examination of the Experimental Data.—Plaskett gives in Table VIII. of his paper (reproduced here in Table III.) the collected mean values of the intensities measured by him, and states that they are probably

accurate to 10 per cent. Examination of his data, however, as shown in Tables III., IV., and VII. of his paper, scarcely supports this, intercomparison of the lines being often indirect and the means being in some cases of two observations only, and especially the inaccuracy in the measurement of the fainter lines seems to be greater. He is, however, willing to concede a possible error of 15 per cent., and indeed, in view of the extreme difficulty and intricacy of the experimental work, he is to be congratulated on so good a result as this and on the perseverance and ingenuity which have made the determinations possible at all. The point I wish to make is not one of criticism of Plaskett's determinations, but to indicate the need, in view of these inevitable inaccuracies, for caution in interpretation of the numerical results, especially as, except in two cases, the measurements of the lines of the Balmer series begin with H_β and not H_α.

While his measured intensities appear to show considerable variations in the relative intensities of the Balmer lines in different nebulæ, these variations are scarcely outside the range that is to be expected from the accidental errors of measurement. For example, let us consider H_γ (the value for H_β is by definition 10, and so no question arises of its variation), the intensity of which has been measured in every one of the eight nebulæ investigated. The mean value of the intensities relative to $H_\beta = 10$ is 4·3, a 15 per cent. error is 0·6, the probable error of these observations (supposing, indeed, they should be identical) is 0·50, and so we should expect to find one of them out of eight differing from the mean by rather more than unity, and this, in fact, is just what Table VIII. shows in the case of I.C. 4593, for which a value of 5·6 is given. The distribution of the set is normal. This is not to say that we contend that there is no variation in the relative intensities of the Balmer lines from one nebula to another, but only that the variations are not sufficiently marked to be revealed with certainty by these measurements, and that for some purposes mean values of the whole measurements are probably more valuable than the measurements for an individual nebula, and it is dangerous to base any arguments for or against any particular mechanism of excitation on these variations, as does Plaskett in rejecting the mechanism of excitation by electron impact on the grounds that the variation of the Balmer decrement is in the opposite direction to that expected from an increase in electron velocity.

Discussion of Possible Mechanisms.—At the outset we must observe that whatever mechanism may be arranged to create excited atoms we must, since they all return to the ground state undisturbed, provide one, if it be not the same, competent to remove them from the ground state at the same total rate as that at which they arrive, *i.e.* $\Sigma N_s \mathbf{A}_s$. There are presumably only two ways of doing this that we need consider, electron collision and radiation.

Examination of our results for the number of creations and for the number of atoms in a given state shows that the number of creations decreases rapidly as the energy of the state increases, but that the number of atoms in a given state is very nearly constant, or at any rate

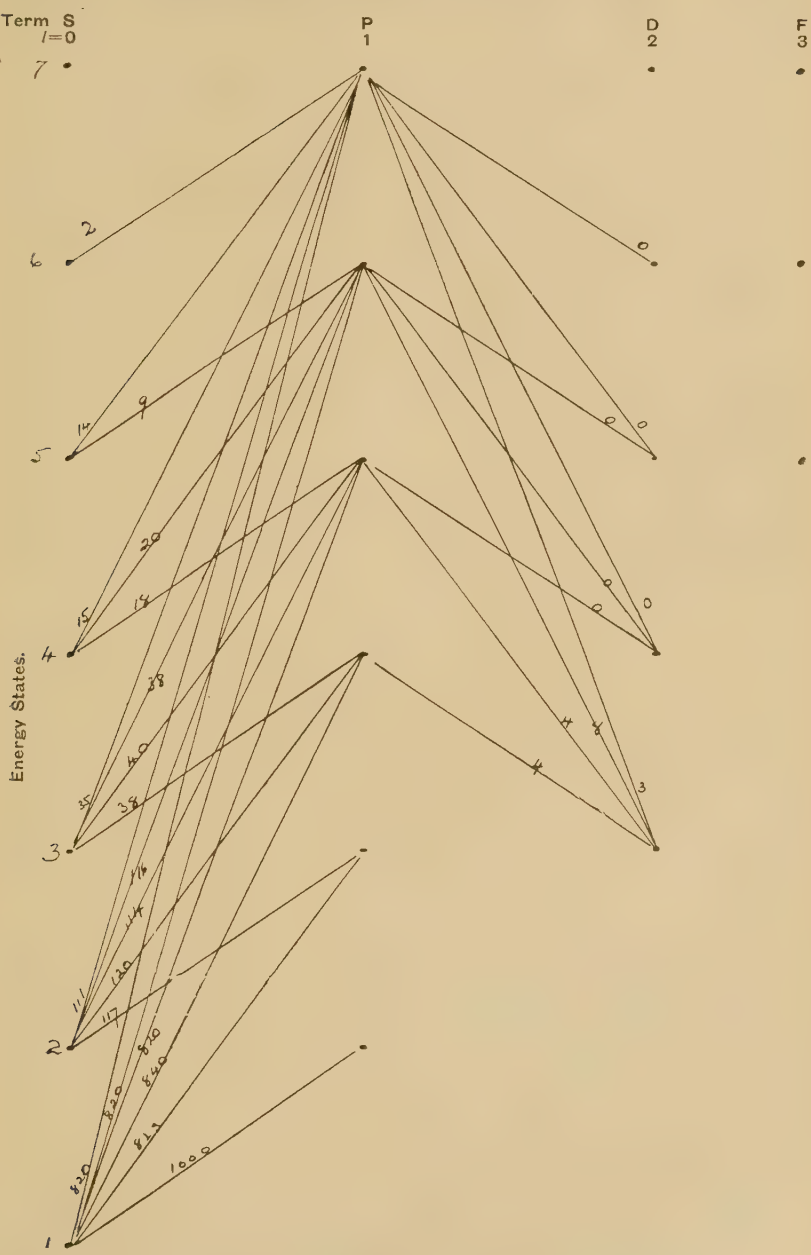


FIG. 1.—Electron Transitions for Excited Atoms created in P states only, 1000 in each P state.

the variation is scarcely outside the range of error of measurement. These remarks, it is true, only apply to states 3, 4, 5, and 6, and we have no direct knowledge of the number of atoms in the ground state or in the ionized state; presumably one or the other of these will be in the vast majority.

We can, however, ignoring the question for the moment of the number of atoms in the ground state or ionized, proceed to compute the numbers of atoms in states 3, 4, 5, and 6 relative to one another for any temperature, assuming that collisions in the nebula are sufficiently frequent to ensure that it behaves as a genuine gas. Eddington has shown that this may be taken to be true for interstellar matter [5], and so holds *a fortiori* for the nebulæ. We will make use, then, of Boltzmann's formula and assign a weight s^2 (*i.e.* the number of sub-states for state s) to state s, since the weight s^2 has been used in computing the transition coefficients and the numbers of atoms in the given states from the observations (also it is likely that nearly all the atoms are ionized).

The data are too scanty to enable one to do anything but determine the order of magnitude of the temperature, but comparison of Table V. or Table VII. with Table VIII. shows that the distribution is consistent with a temperature of about 10,000°, and that 5000° is too small and 50,000° too large from this point of view.

Table VIII.

Relative Numbers of Excited Atoms.

$s^2 e^{-h\nu/kT}$.

T. / s.	$5\cdot10^3$.	10^4.	2×10^4.	5×10^4.
1	$1\cdot41\times10^{11}$	$1\cdot23\times10^5$	$1\cdot20\times10^2$	1·82
2	33·8	3·88	1·32	0·69
3	25·8	1·21	0·65	0·52
4	1·00	1·00	1·00	1·00
5	0·77	1·10	1·32	1·46
6	0·76	1·35	1·72	2·02

We have now to examine the possibilities of stimulation by electron collision. The average energy of an electron corresponding to a temperature T is $1\cdot293\ T/10^4$ volts. The excitation potential for H_α is 12·0 volts and the ionization potential of hydrogen is 13·54 volts. The following formulæ hold for the energy distribution of electrons:—

Let $\mathbf{E}$ = number having energy E volts; L = total number.

$$\mathbf{E} = CEe^{-\frac{11580\,E}{T}}.$$

$$\bar{E} = 1\cdot293\ T \times 10^{-4}.$$

$\mathbf{E}$ is a maximum at $E = \cdot669\ \bar{E}$; $C = 1\cdot340 \times 10^8\ L/T^2$.

Let $\mathbf{L}$ = number having an energy $\geqslant$ E.

$$\frac{\mathbf{L}}{L} = \left\{1 + 1\cdot158\,\frac{E}{T}\cdot 10^4\right\} e^{-\frac{11580\,E}{T}}.$$

Table IX.

Percentage of Electrons in a Gas at Temperature T, having an Energy ⩾ E volts.

S.	E.	$T=10^4$ deg.	$T=10^5$ deg.
2	10·14	0·01	68
3	12·04	0·0013	59
4	12·74	0·00065	56
5	13·01	0·00047	56
6	13·14	0·00041	55
7	13·28	0·00035	55
$\bar{E}_{10,000°}$	1·293	57·5	
E_{max}	·864	74·1	
$\bar{E}_{100,000°}$	12·93	..	58
E_{max}	8·64	..	74

Table IX. gives the numerical values for 10,000° and 100,000°. It will be seen that at 10,000° direct stimulation from the ground state can scarcely be of any importance, which lends support to the view that the excited atoms are formed by capture of an electron by an ionized atom.

Plaskett remarks that an increase of electron velocity will result in a decrease of Balmer decrement, since more atoms will be lifted to upper states, and consequently if the presence of *He* II 4686 in nebulæ may be regarded as a sign of high electron velocity it follows that, for the mechanism of excitation by electron impact, slow decrement in the Balmer series should be a necessary condition for the appearance of this line. He points out that his results show the opposite to be true, and concludes, therefore, that Balmer lines in nebulæ are not excited by electron impact. This argument is fallacious for this reason: If $\bar{E}$ be the mean energy of electrons in a gas at temperature T, the greatest number of electrons have an energy of about two-thirds of this, and while raising the temperature will, it is true, raise the absolute number of electrons with higher energies than any arbitrary amount, it does not follow that they are raised relatively to those of lower energy unless the energies concerned are all less than this value $\cdot 67\bar{E}$; otherwise raising the temperature, while increasing the stimulation of all states, would increase the lower states more than the higher.

The present writer agrees that electron impact is ineffective in producing the Balmer lines, but on the grounds of numerical inadequacy at any temperature consistent with other requirements.

Ionization.—In discussing the ionization we shall make use of an approximate method due to Eddington (6), who has pointed out that, in interstellar material of density ρ in equilibrium with radiation diluted by a factor δ, the ionization corresponds to that in material of density $\rho\delta$ in equilibrium with undiluted radiation.

The standard equation for an equilibrium state is

$$\log \frac{x}{1-x} = -\frac{5080\mathrm{I}}{\mathrm{T}} + \frac{5}{2}\log \mathrm{T} - 6{\cdot}5 - \log p_e,$$

where x is the fraction of atoms ionized.

The nebular material may be far from thermodynamic equilibrium, but this equation used for a density $\rho\delta$ will at least give the orders of magnitude involved. For $\rho = 10^{-20}$ gms./c.c. $p_e = 10^{-19}\mathrm{T}$ atmospheres roughly. This leads, then, to the equation (since I = 13·54)

$$\log \frac{x}{1-x} = -6{\cdot}85 \times \frac{10^4}{\mathrm{T}} + \frac{3}{2}\log \mathrm{T} + 12{\cdot}5 - \log \delta \quad . \qquad (4)$$

Let the radiation be represented over the range of wave-length in question by black-body radiation of normal density divided by δ. This dilution factor δ is not known precisely, but it will be seen that its limits can be fixed fairly precisely by taking into account the fact mentioned above that atoms must be undisturbed during the duration of an excited state.

Let B_{12} = probability of a transition by absorption from state 1 to state 2 in unit time in radiation of unit density (*i.e.* with $1/h\nu$ quanta present),

Also $\mathrm{B}_{12} = \mathrm{A}_{21}c^3/8\pi h\nu^3$.

Let b_{12} = probability of absorption per sec. per quantum per c.c.

$b_{12} = \mathrm{B}_{12}h\nu$.

$= \mathrm{A}_{21}c^3/8\pi\nu^2$.

Table X. gives the values for the Lyman, Balmer, and Paschen series.

Table X.

Lyman.		Balmer.		Paschen.	
b_{12}	$8{\cdot}34\times10^7$	b_{23}	$2{\cdot}27\times10^8$	b_{34}	$3{\cdot}79\times10^8$
b_{13}	$7{\cdot}05\times10^6$	b_{24}	$2{\cdot}38\times10^7$	b_{35}	$4{\cdot}34\times10^7$
b_{14}	$1{\cdot}43\times10^6$	b_{25}	$5{\cdot}71\times10^6$	b_{36}	$1{\cdot}13\times10^7$
b_{15}	$4{\cdot}44\times10^5$	b_{26}	$2{\cdot}05\times10^6$	b_{37}	$4{\cdot}10\times10^6$
b_{16}	$1{\cdot}82\times10^5$	b_{27}	$8{\cdot}68\times10^5$	b_{38}	$1{\cdot}85\times10^6$
b_{17}	$8{\cdot}88\times10^4$	b_{28}	$4{\cdot}15\times10^5$	b_{39}	$9{\cdot}65\times10^5$
b_{18}	$5{\cdot}01\times10^4$	b_{29}	$2{\cdot}10\times10^5$		

The number of quanta per angstrom is given by

$$\mathrm{Q} = 8\pi\frac{\nu^4}{c^4}10^{-8}\Big/e^{\frac{h\nu}{k\mathrm{T}}} - 1$$

and is tabulated below.

Thus the probability of an atom in state 3 absorbing in 1 second, if Q quanta are present, per c.c. is about $4{\cdot}8\ \mathrm{Q} \times 10^8$. The mean life of an atom in state 3 is $2{\cdot}26 \times 10^{-8}$ sec. if undisturbed, so that the probability of absorption by an excited atom in state 3 = 10 Q.

TABLE XI.

The Number of Quanta of Hydrogen Radiation per c.c. per angstrom in Black-body Radiation.

Q_{rs} means the number of quanta corresponding to the transition *rs*.

	$T=10^4$ deg.	$T=10^5$ deg.
(1) Lyman Series :		
Q_{12}	$7{\cdot}8\times10^{7}$	$5{\cdot}12\times10^{12}$
Q_{13}	1·95	7·35
Q_{14}	1·10	8·44
Q_{15}	0·87	11·20
Q_{16}	0·79	9·05
(2) Balmer Series :		
Q_{23}	$1{\cdot}53\times10^{9}$	$1{\cdot}09\times10^{10}$
Q_{24}	2·38	3·35
Q_{25}	2·63	5·09
Q_{26}	2·74	6·29
(3) Paschen Series :		
Q_{34}	$1{\cdot}74\times10^{8}$	$2{\cdot}53\times10^{9}$
Q_{35}	4·41	7·75
Q_{36}	6·47	1·25
Q_{37}	7·59	1·58

Now in undiluted black-body radiation the number Q for lines of the Paschen series (taking a width of 1 A.) is about 2×10^{9} at 10^4 deg. and about 3×10^{10} at 10^5 deg. In fact the probability is

10^4 deg. $\quad 8\{6{\cdot}59 + 1{\cdot}91 + 0{\cdot}73 + 0{\cdot}31 + \ldots\}2{\cdot}26\times10^{-8}\times10^{16}$,
10^5 deg. $\quad 8\{9{\cdot}60 + 3{\cdot}44 + 1{\cdot}41 + 0{\cdot}65 + \ldots\}2{\cdot}26\times10^{-8}\times10^{17}$,

i.e. at 10^4 deg., $2{\cdot}1\times10^{9}\,\delta$; at 10^5 deg., $3{\cdot}4\times10^{10}\,\delta$.

This fixes the dilution factor, since we must make it unlikely that an atom is disturbed. We must, since we have to allow for the "forbidden" lines, make it very unlikely for a hydrogen atom to be disturbed, so that δ should be at least 10^{11}. Ordinary interstellar radiation has a dilution factor of 10^{14}, so that δ must lie between these limits :

$$10^{11} < \delta < 10^{14}.$$

A simple consideration due to Eddington confirms this value, indeed inclining one to the supposition that the radiation is not much more dense than in interstellar space, but presumably it is richer than the average in short-wave radiations, due to the proximity of a nearby early type star. Consider, for example, the ring nebula in Lyra. Its apparent diameter is about 1′ of arc, so that we can at once determine the brightness of the central star to an observer situated on the out-

skirts of the nebula since its ratio to the brightness as observed from the earth will be about $3600^2 : 1$; that is a change of about 12·5 magnitudes. The central star of this nebula has a visual magnitude 15·4 and a photographic magnitude of about 13. It is thus a hot star of early type and has an apparent magnitude from the outskirts to the nebula of about 1 ; that is to say, the circumstances are in accord with the supposition that the material is under the influence of black-body radiation corresponding to 10,000 to 20,000° diluted by about 10^{13}.

Thus we see that the hydrogen atoms are probably nearly all ionized, for equation (4) gives complete ionization for $T = 10^5$ deg.; indeed too complete, since $\frac{x}{1-x} = 2{\cdot}04 \times 10^{19-\delta}$. For $T = 10^4$ deg., $\frac{x}{1-x} = 4{\cdot}5 \times 10^{11-\delta}$.

Table XII.

Table of Fractions of Ionized Atoms.

T. \ δ.	10^{11}.	10^{12}.	10^{13}.	10^{14}.
10,000	0·82	·031	·043	·0045
20,000	1·000	1·000	·998	0·97
15,000	1·000	·994	0·94	0·62
100,000	1·000	1·000	1·000	1·000

Thus a fair compromise seems to be $\delta = 10^{13}$ (or if ρ be less, say 10^{-21}, then $\delta = 10^{12}$) and about 10 per cent. of hydrogen atoms not ionized.

Lyman Absorption.—We have shown that Lyman absorption is unlikely to be an important mechanism, but nevertheless, for the sake of completeness and also since it must occur if any atoms at all are in the ground state, we shall proceed to discuss numerical magnitudes involved. The figures given below show that there is no inconsistency of the data with the occurrence of Lyman absorption, but that it is not adequate to maintain by itself the observed conditions. It is of interest chiefly for two reasons: firstly, it is unsafe to dogmatize about the conditions in nebulæ, so this process must be looked into ; and, secondly, it affords a method of determining the temperature of the exciting radiation, since this must be so constituted as to create atoms in excited states in exactly the proportion deduced from equations (3), and not, be it observed, from equations (1) or (2), which Plaskett's discussion seems to imply.

The relative numbers of creations by Lyman absorption are given by

$$N_{1s} = N_1 A_{s1} \frac{1}{e^{\frac{h\nu}{kT}} - 1} d\nu \quad . \quad . \quad . \quad (5)$$

or by

$$N_{1s} = N_1 b_{1s} Q_{1s} \quad . \quad . \quad . \quad . \quad . \quad (6)$$

This leads to the following figures :—

Table XIII.

Creations by Lyman Absorption.

	10,000°.	100,000°.
p_3	870	432
p_4	100	100
p_5	24	42
p_6	9	14

The figures for 10,000° are quite inconsistent with Table VI., and even at 100,000° the gradient is still far too rapid, though, since at this temperature there would be no atoms to absorb, the table is merely a *reductio ad absurdum.*

It may be observed that the relative numbers should for this process vary as $e^{-h\nu/kT}$ not $s^2e^{-h\nu/kT}$, for only P states are involved, and they have all the same weight. This explains the fact that a comparison of Table VII. with the figures of Table VIII. divided by s^2 yields a temperature of about 10,000°, for the appropriate transition coefficients differ in about the same ratio.

Electron Capture.—This appears, in view of the present figures, to be the most probable mechanism of the production of excited atoms. The encounters capable of resulting in a capture must be about equally likely for atoms in states 3, 4, 5, and 6, and since the numbers in these states turn out to be about equal, the capture coefficients, which in this case will be the same as the p's, should be roughly proportional to the total transition coefficient. The tables and fig. 2 show this to be the case.

Unfortunately there does not exist any exact theory of the capture of electrons by hydrogen nuclei comparable with our knowledge of the transition coefficients. It is presumably only a matter of time before such a theory is developed, but in the meantime we have only Kramers's original theory or Milne's (7) modification of it. It so happens that for the temperatures likely to obtain in nebulæ the mean electron speeds make the use of these formulæ difficult; but it may be observed that for high temperatures the capture coefficients tend to vary as $1/s^3$, and our data give a result in accord with this, as may be seen from the last column of Table IV.

Zanstra's discussion (8) of the photo-electric ionization in nebulæ by the light of nearby stars shows that this mechanism is possible and adequate, and his requirement of a temperature for the associated star of about 20,000° is in accord with our present results, since we seem to need something not much over 10,000° and well under 50,000°.

One further consideration remains, that of balancing.

We must have

Number of ionizations = number of recombinations.
= number of atoms arriving at ground state.
= number of quanta absorbed.

The radiation we cannot well check, since the continuous absorption

coefficient is unknown. We can, however, examine captures and transitions.

If x be the fraction of ionized atoms

y „ „ excited neutral atoms

$y(1-x)\,.\,N\,.\,5\times10^{8}$ = number of transitions /c.c. sec.

$\leqslant$ electron encounters with ionized atoms

$= \pi\,.\,L\,Nx\,.\,10^{-8}\sqrt{T}.$

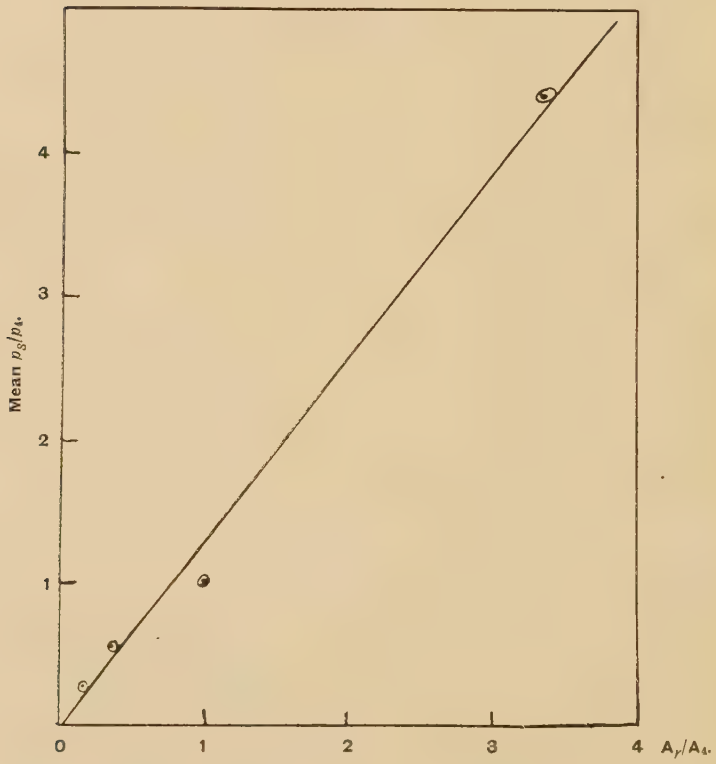


Fig. 2.—The Relation between Excited Atoms and Transitions.

This leads, for L = 500, to

$$\frac{x}{1-x} \geqslant 3y10^{13}/\sqrt{T}.$$

The ratio is uncertain by a factor of about 10, but at any rate $\frac{x}{1-x}$ should be of the order of magnitude of $10^{14}y/\sqrt{T}$.

We have

T =	5000	10,000	15,000	20,000
$10^{14}y/\sqrt{T}$	$1{\cdot}4\times10^{1}$	10^{6}	8×10^{7}	7×10^{8}.

Table XII. shows the values of x for various δ, and the comparison shows that for the assumed density a temperature rather below 10,000° is required and a small dilution factor, *i.e.* even less than 10^{12}; this shows presumably that our estimate of ρ is too high and that a density of about 10^{-21} or 10^{-22} would be better, but this examination is too rough to be more precise.

In conclusion, then, we may say that in the nebula :

1. Hydrogen atoms are nearly all ionized.
2. The temperature is of the order of 10,000°.
3. The Balmer emission lines are generated by electron capture by ionized atoms and their subsequent transitions.
4. The dilution of the radiation is of the order of 10^{12}.
5. The density is of the order 10^{-21} gms./c.c.
6. While Lyman absorption must occur, indeed not much less or more frequently than ionization, it has little effect in producing Balmer lines.
7. The mechanism of ionization is presumably photo-electric rather than electron collision or line absorption.

References.

(1) H. H. Plaskett, *H.C.O. Circ.*, 335, 1928.
(2) I. S. Bowen, *Ap. J.*, **67**, 1, 1928.
(3) A. S. Eddington, *M.N.*, **88**, 134, 1927.
(4) F. G. Slack, *Phys. Rev.*, **31**, 527, 1928.
(5) A. S. Eddington, *Internal Constitution of the Stars.*
(6) A. S. Eddington, *ibid.*
(7) E. A. Milne, *Phil. Mag.*, **47**, 209, 1924.
(8) H. Zanstra, *Ap. J.*, **65**, 50, 1927.

The Total Eclipse of the Sun, 1929 *May* 9, *observed in the Philippines.*

By R. L. Waterfield. (Plate 13.)

Plans were made by Dr. H. K. Hartline of the Johns Hopkins University, Mr. W. E. B. Lloyd, and myself to observe the total eclipse of the Sun on 1929 May 9, from Iloilo in the Philippines. The instruments were made, tested, and adjusted in the observatory of the Johns Hopkins University. Unfortunately Dr. Hartline was prevented from accompanying us on the expedition ; he played, however, the most active part of any in the preparations and in the discussion of the results.

The Objects in View.

(1) The photography of the infra-red flash spectrum at both second and third contacts from λ 7000 to λ 9000 with moderate dispersion. We also intended to give a long exposure on the same region of the corona spectrum.

(2) The direct photography of the corona on panchromatic and infra-

red plates, using filters to cut out varying extents of the shorter wave-lengths. In this way we hoped to find out to what extent one could reduce the scattered light and gain greater coronal extension; and whether or not the shape of the corona, and the distribution of its light, were the same for different wave-lengths.

(3) The use of an occulting shutter roughly to equalize throughout the intensity of the coronal image.

The Instruments.

(1) Concave grating, $2\frac{1}{2} \times 3$ inches aperture; 57 inches focus; 15,000 lines per inch; mounted objectively. Infra-red sensitive plate (Eastman), neo-cyanin. This grating is intensely brilliant in the first order red on one side.

(2) Coronagraph, $7\frac{1}{4}$-inch visual lens by Ross, 11-foot focus. Wratten & Wainwright panchromatic plate; Ilford tricolour filter, transmitting wave-lengths longer than λ 5800. One exposure of 200 seconds, reduced by occulting shutter to 3 seconds at the sun's limb.

(3) Coronagraph, 3-inch rapid rectilinear lens by Beck, 2-foot focus. Infra-red, neo-cyanin plate (Eastman), and W. & W. filter 88 A, transmitting wave-lengths longer than λ 7200. One exposure of 200 seconds.

These three instruments were mounted on one equatorial head and driven directly on the sun.

(4) Coronagraph, 5-inch visual lens by Alvan Clark, 6-foot focus; Imperial Dry Plate Company, H. and D. 2000, panchromatic plate, and Ilford "Beta" filter transmitting λ 4450 to λ 6950. Ten exposures ranging from $\frac{3}{4}$ second to 40 seconds. This camera was mounted on a separate equatorial head and driven directly on the sun by a "long arm" and falling clock weight.

The Expedition.

On arriving in Iloilo, on the south-east coast of the island of Panay, thirteen days before totality, we found that Father Selga (Director of the Weather Bureau in Manila) had with great kindness carried out our request to select us a site and have our two concrete piers erected. This saved us several days delay. The Principal of the Normal School generously gave us the use of the school-field and a large hall for our camp and workshop, situated in La Paz, about a mile north-west of Iloilo.

Our greatest difficulty was in preparing the infra-red plates, already dyed with neo-cyanin by the Eastman Company, which have to be bathed in ammonia just before use. Owing to the heat and humidity the emulsion would melt on removing it from the iced bath for drying with the electric fan. It was only after Mr. Casanave, a photographer in the town, allowed us to have his dark-room, specially cooled it through the night, and permitted us to use it in the early hours of the morning, that we began to get good plates. Even so they gave much trouble;

and in the dawn of the eclipse day I spent five hours getting three plates prepared.

A week before the day we were joined by Professor Ortigas of the University of the Philippines, who was of the utmost value to us in helping with the preparations and acting as interpreter. Finally, Commander Kepler, U.S.N., in command of the U.S. Naval Observatory Expedition on the beach in Iloilo, kindly put at our disposal the services of three sailors who attended our rehearsals and gave valuable assistance in the carrying out of our programme.

A few minutes before totality the shutter of the spectrograph jammed open. A rough cover rigged up at the moment was out of my reach from where I was observing the flash visually; so its working had to be added to Mr. Lloyd's already complicated job of making the last adjustments on the occulting shutter. Frank M'Cree, B.M., 1/c, U.S.N., counted 10-second intervals before and each of the 222 seconds of totality after my signal, "Go," at second contact. Professor Ortigas exposed the 11-foot and infra-red coronagraphs; Mr. Lloyd and myself exposed and changed plates respectively on the 6-foot camera, returning to the spectrograph for the second flash; while R. M. Holberg, Seaman 1/c, and C. H. Norton, Seaman 2/c, U.S.N., handed up, and relieved me of, the plateholders. The long exposure on the corona spectrum, which anyhow would have been spoilt by the clouds, was stopped prematurely by a wind blowing shut the temporary cover.

Just before totality a veil of high cirrus came over the sun, and increased in opacity as totality proceeded. At the sun's altitude of nearly 36 degrees we got, as far as can be judged from plates, etc., about half the light we got at Giggleswick in 1927 with an altitude of only 10 degrees; at the end of totality it was still more overcast.

Results.

The lack of light ruined the flash spectra; and only four emission arcs, including the infra-red Ca^+ group, $\lambda\lambda$ 8498, 8542, 8662, appear on the two plates.

In the 11-foot coronagraph the plate—the only one of its make used—had deteriorated badly and showed here and there only traces of the roots of the streamers.

In the 6-foot coronagraph seven plates are sharp, three show vibration. All, with the exception of the shortest ($\frac{3}{4}$ second) exposure, bring up the stratified structure of the cirrus which sadly confounds the coronal detail. The short exposures show a lot of fine detail; a large slender prominence on the following limb; an intense coronal arch on the preceding limb; fine polar plumes; and a maximum-type corona with five main streamers, one of which, tapering to a slender point, can be traced to between five and six solar radii from the south limb. Although the clouds rendered the quality of our plates greatly inferior to that of the long exposure, short focus, non-panchromatic plates of the U.S. Naval Expedition, it is interesting to note that ours show practically the same extension as theirs. Undoubtedly our violet and

blue absorbing filter saved us from a mere halo of haze ; while it seems probable that in a cloudless sky we might have got yet greater extension with its use.

The single 200-second exposure taken with the F8 infra-red camera is the only plate to bring up no sign whatever of cloud detail, and there is upon it only slight general fogging. Yet the exposure must have been equivalent to about 20 seconds on the F14·5 6-foot camera with a plate certainly not more than forty times as fast. On this infra-red plate the inner corona is very intense and burnt out to a greater distance from the limb than on any but the longest of the panchromatic exposures ; yet the corona extends to little more than one radius from the limb, has a remarkably abrupt edge, and shows only the bases of the streamers.

In view of the extraordinary difference between the infra-red and the panchromatic plates, I made twenty-five tracings on both the infra-red and the $\frac{3}{4}$-second exposure panchromatic plates with the Moll automatically recording densitometer of the Johns Hopkins University. The tracings were made along parallels of declination, some of them cutting the sun's disc as chords of varying length, while those towards the north and south traversed only varying depths of the corona. Dr. Hartline and myself then measured some twenty points on each curve, and were thus able to plot the intensities of about four hundred separate points for each of the two negatives. By suitably joining these points we got, for each negative, ten contours round the corona of equal intensity. On superimposing the two contour charts it was found that contours with the same distance from the sun's centre were practically identical—the slight divergences being easily explainable as the result of unequal fogging of the two plates.

But the chief interest of the infra-red plate is the fact that the intensity of the coronal image falls off far more rapidly as one passes outwards from the limb than it does on the panchromatic plates. The effect, we felt from the first, could not be attributed entirely to a purely photographic cause—a steeper intensity gradient in the infra-red plate. Unfortunately no quantitative analysis could be made : for, owing to the uncertainty of completely drying the infra-red emulsion after sensitizing, we did not dare imprint upon it the photometric squares we had intended. Nevertheless, on returning to England, Dr. Hartline and I carried out two tests which we consider to be fairly conclusive. We rephotographed a transparent positive made from the $\frac{3}{4}$-second panchromatic exposure with both infra-red and panchromatic plates, giving with each many different exposures ; and in no case were we able to reproduce the kind of difference existing between the original infra-red and panchromatic negatives, as we should have been able to do had the latter effect been purely photographic. The other test consisted in imprinting on infra-red and panchromatic plates (spread with emulsions of the *same number* as the originals, but out of *different batches*) photometric squares, using large ranges of intensity and exposure. We found there was extraordinarily little difference in the intensity curves of the two kinds of plates. One knows, of course, the surprising eccentricities

A

B

A. Infra-red plate. Exp. 200 sec. Eastman Neo-Cyanin plate hypersensitized in ammonia. Wratten & Wainwright filter 88 A. 3-in. photographic lens (Beck), 24-in. focus.

B. Panchromatic Plate. Exp. $\frac{3}{4}$ sec. 5-in. Alvan Clark lens (visual), 6-ft. focus. Beta Ilford filter

of plates even out of the same box developed or even exposed under different conditions. It is therefore impossible to try to decide the question definitely. The experiment must be repeated at a future eclipse, which—for the sake of the infra-red plates—should not be in the Tropics.

It is interesting to remember in this connection that the photographs taken by Drs. Pettit and Nicholson at the 1925 eclipse showed an analogous effect. When measured on the Koch microphotometer of the Mount Wilson Observatory the plate taken in the visual region of the spectrum gave a somewhat more rapid falling-off in coronal intensity on passing out from the limb than did either of the two plates taken in the violet-blue region. The difference they found was much smaller than that which we require to explain our plates; but that would be due to our working with longer wave-lengths—λ 8200 being the effective wave-length of our infra-red and λ 5700 of our panchromatic plate.

If our results are confirmed they would seem to show that the light of the outer corona and streamers is not pure reflected white light, but, to some extent at least, light scattered selectively according to the law of the inverse fourth power of the wave-length, and therefore poor in infra-red rays. From this it would follow that the degree to which one can overcome the scattering of light by the sky in an attempt to gain coronal extension is limited; while the optimum effect is to be got by cutting out all the upper part of the spectrum above a certain limiting wave-length somewhere between the green and the visible red.

Conclusions.

1. The shape of the inner and middle corona is the same in visual and near infra-red light.

2. It is probable that the infra-red light of the corona falls off much more rapidly in intensity on passing radially outwards than does the visual light: that the outer corona and streamers are very poor, or lacking, in these longer rays.

3. The use of filters absorbing the shorter wave-lengths with panchromatic plates is of great advantage in bringing out streamers despite high thin cloud; while, under the same conditions, infra-red plates give yet greater advantages as regards the inner and middle corona.

Finally, we wish to say how deeply indebted we are to those who made our expedition possible: to the authorities of the Johns Hopkins University and Hospital who granted me leave of absence from my duties; to the Department of the Navy in Washington, and the Superintendent and Staff of the U.S. Naval Observatory, for many privileges extended to us during our visit and on the return journey; and to the Baltimore and Ohio Railroad Company for their special arrangements for the transport of our instruments. We wish to thank Prof. R. W. Wood, Mr. Melotte, Mr. Leon Campbell, Mr. C. W. Elmer, and Mr. Henry for the kind loan of various pieces of apparatus, and Mr.

D. T. Bonney for his help during our preparations in Baltimore. Above all are we indebted to the people of Iloilo and Manila : to Father Selga, by whose advice we were guided from the beginning, and who gave us so much of his time in Iloilo whether in the eclipse camp or in those delightful expeditions he arranged for us ; to Professor and Mrs. Edward Hyde who entertained us with such kindness all the time we were in Manila ; and to the many other friends we made whose kindnesses to us will always keep this expedition outstanding among our pleasantest recollections.

Baltimore :
1930 *February* 26.

Positions of the New Planet from Photographs taken at the Radcliffe Observatory, Oxford.

(*Communicated by the Radcliffe Observer.*)

Photographs of the new planet have been obtained with the 24-inch refractor on four nights, March 21, 24, 29, and April 2. The night of March 24 was an unusually good one, the atmosphere being very transparent and the seeing steady ; the other nights were inferior. The first, second, and fourth plates were taken by Mr. W. H. Robinson, the third by Mr. H. G. Scott Barrett, who measured and reduced all the plates. The first two plates were given two exposures to enable the planet to be identified by its motion between the exposures ; the other two plates have single exposures on them.

The reduction was carried out by means of Schlesinger's dependence method as modified by Comrie,* the same two sets of three stars being used for each plate. These stars appear in two of the Paris Astrographic Catalogues, as follows :—

Star.	Tome II. A 110.		Tome III. A 105.
1	490	=	84
2	543	=	103
3	595	=	114
4	525	=	98
5	537	=	102
6	565	=	108

The planet was thus referred to each astrographic plate through the two sets of comparison stars, the means taken, and the positions reduced to spherical co-ordinates by the catalogue tables. The second astrographic plate was found to give positions greater by $0^s{\cdot}02$ in R.A. and less by $0''{\cdot}6$ in Declination in each case. The resulting positions given below are the means of those derived from the two astrographic plates, and are corrected for magnitude error.

* *B.A.A. Journal*, **39**, 203, 1929.

Plate.	Exp.	Date. G.M.T.	R.A. (1930·0).	Declination.
	m.		h m s	° ′ ″
1(*a*)	36	1930 Mar. 21·865	7 15 35·00	+22 7 48·4
1(*b*)	41	·897	34·97	7 48·5
2(*a*)	51	24·842	32·47	8 5·2
2(*b*)	50	·886	32·44	8 5·6
3	60	29·853	30·34	8 29·5
4	63	Apr. 2·870	30·51	8 45·5

To enable the positions to be corrected at any time for revised places of the comparison stars, the dependences are given to two places.

DEPENDENCES.

Plate. / Star.	1.	2.	3.	4.
1	·34	·35	·36	·35
2	·31	·33	·36	·38
3	·36	·32	·28	·28
4	·51	·58	·62	·59
5	·17	·18	·21	·24
6	·32	·24	·18	·17

The planet was observed visually in the 18-inch refractor on the nights of March 29 and April 2, the observations being confirmed in each case by subsequent inspection of the photographs. Its visual brightness was estimated as being slightly greater than that of a star 2′*sf*, than which it was very slightly fainter photographically. Its photographic magnitude is estimated as 15.

The Spectrum of β Lyræ. By the late F. E. Baxandall, A.R.C.Sc. (Abstract.)

(*Communicated by the Director, Solar Physics Observatory, Cambridge University.*)

The following paper is an abstract of an investigation nearly completed by the late F. E. Baxandall, and edited for publication in the *Annals of the Solar Physics Observatory* * by Dr. F. S. Hogg and the Director. Spectrograms secured at South Kensington and Cambridge have been examined and compared with the spectrograms used by the late R. H. Curtiss at Allegheny in his comprehensive memoir on β Lyræ; † these plates were very kindly lent for comparative study. The complex spectrum of β Lyræ includes an oscillating spectrum of type B8 with a velocity range of about 370 km./sec.; an absorption

* Vol. ii., part i. (in the press). † *Publ. of the Allegheny Obs.*, ii., 1911.

spectrum of type B5, displaced to the violet, which is only well visible for half the light cycle, and which shows an uncertain variation in its velocity displacement; a weak, displaced absorption spectrum of about the same type occasionally present and displaced to the red; undisplaced absorption lines H and K due to Ca^+; and bright bands of hydrogen and helium of varying intensities and positions.

Points of special interest in the spectra have been noted as follows: The B8 spectrum can be measured throughout, which is inconsistent with the explanation of the light curve as that of an ordinary eclipsing variable in which the B8 component should sometimes be completely hidden. In the B5 spectrum the helium line at $\lambda 3964{\cdot}73$ is unusually strong and is frequently double, in addition to having other usual components present. This line is lacking in the spectrum of lines slightly displaced to the red, which might otherwise be regarded as being merely the B5 spectrum displaced by orbital velocity. A simple B5 spectrum displaced by orbital velocity in the opposite sense to the B8 spectrum would fit a number of observed data, but not all. The bright bands shift over from one side to the other of the undisplaced positions of the lines as the B8 absorption component moves through the undisplaced position in the opposite sense. But this simple statement must be qualified by adding that whereas when the B8 lines are displaced to the violet the bright bands lie wholly to the red, they lie to the violet with occasional extensions on the red side, when the B8 lines are displaced to the red; also in the case of $H\beta$, for which line the B8 absorption line is very weak, the red wing of the bright band is present throughout. The bright bands are accompanied by broad wings showing a number of weak components, some of which become markedly stronger at certain phases in the light cycle.

The following model is suggested as best fitting the spectroscopic results, though it is not to be regarded as finally satisfactory. There are two ellipsoidal stars of spectral types B8 and B5. The B5 star is the larger but less massive star, with a brighter surface. The B5 star is surrounded by a gaseous envelope, larger than the B8 star, transparent to the radiation from both stars, and radiating a broad, bright line spectrum of hydrogen and helium.

An Error in Star Catalogues concerning B.D. + 35°, 1508.

By F. A. Bellamy and Ethel F. Bellamy.

The computations referring to the Vatican Astrographic Catalogue, zones + 55° to + 64°, have been carried out at the University Observatory, Oxford. The photographic measures (made in Rome under the general superintendence of Father Hagen, S.J., by ladies of a religious hospital Order) were compared with meridian places of the Gotha, Helsingfors, and Harvard Catalogues of the Astronomische Gesellschaft, in the first instance to determine the constants of the plates;

and secondly, the differences are available for studying the places of individual stars. These differences have been collected in the ledgers, as was previously done for the Oxford zones, which are now under scrutiny by the writers of this note; and cases of possible proper motion, variability, duplicity, etc., are being examined, as well as cases of small errors.

Occasionally a more important error is found, and the instance which follows seems worthy of being noted, as it was not tracked down without a good deal of trouble, some of which may be saved to others.

It will be seen that the star B.D. + 35°, 1508 should not have come within these zones (which deal with declinations from + 54° to + 65°), but a mistake of 20° was made in declination, which was copied as + 55° instead of + 35°.

The star was given by Espin in *A.N.*, 3559, as 1288 + 35°, 1508 : $6^h\ 45^m{\cdot}9$, + 35° 37′ (1900), $9^m{\cdot}0$ (B.D.), Espin 9·1, colour OR, spectrum III. !!, 1898 February 16. It was included in *Pub. Spec. Vat.*, **7**, p. 40, No. 1944, B.D. 1508 : $6^h\ 45^m\ 53^s$, + 35° 37′·2 (1900·0), $8^m{\cdot}6$, spectrum III. 2, C 7·7, E. var. ? ; but on p. 128 of the same work the declination unfortunately appears as + 55°, thus—1944, Lynx. B.D. 1508 : $6^h\ 42^m\ 53^s$, + 55° 39′·8 (1855·0). The error is emphasised by the attribution of the star to the constellation Lynx instead of Auriga or on the boundary of Gemini.

The error then found its way into the *Astron. Abhand. A.N.*, Band **8**, Nr. 1, *Verzeichnis von* 2191 *verdächtigen Sternen*, p. A 15, No. 580, $6^h\ 42^m\ 53^s$, + 55° 39′·8, $9^m{\cdot}0$ III., with references to the *Spec. Vat.* as above, also to *Mitt. V.A.P.*, **24**, 163 : the latter reference has not been verified.

It was in using this Verzeichnis that we came across the puzzle of having a suspected variable star with declination + 55°, which did not appear to be in the Helsingfors Catalogue nor on the Vatican plates, which give stars down to the 12·5 or 13·0 mag.

University Observatory, Oxford :
1930 *April* 2.